Creating computer games that are controlled by EEG helmets

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***Abstract*— Electroencephalography (EEG) and a brain-computer interface (BCI) are relatively young technologies, that in some cases could replace the classic computer mouse control. We are using EEG and BCI to control computer games, which have always been very popular with people of all ages. In the paper, we focus on using the Epoc helmet for controlling two games, which we created in the Unity game engine. In the first game "Ball and Mind" the player's task is to navigate a ball from start to finish through a maze. The second game, "Objector of Mind", is focused on avoiding obstacles with an Epoc helmet. The player controls a cube and he has to avoid obstacles that come to him with a gap.**

Keywords—EEG, BCI, Emotive, Epoc, Insight, Unity, games

I. Introduction

Today, technologies make our lives easier every day - they help us in our homes, at work, and in our free time. Some people can no longer imagine their existence without them - especially people who are bedridden, cannot speak or move their body (they are paralysed) can use electroencephalography (EEG) and the brain-computer interface (BCI) technology. The BCI applications based on EEG use a non-invasive technique to measure brain activity. The captured signals are then fed into machine learning algorithms. Machine learning algorithms are designed to capture EEG brain activity associated with certain emotions, actions, and expressions. When the algorithms identify the corresponding brain activity captured through the EEG, the BCI then transfers the commands to an external device such as a robotic arm, a wheelchair, or just within the local device to a specific programme that records the command and executes the defined functionality.

Richard Caton in 1875 used a galvanometer to detect small electrical signals that occurred in nerve cells and made the first known neurophysiological recordings with animals. These animal experiments were necessary to confirm that nerve cells use some form of electricity as a means of transmitting information. The development of recording electrical activity took another half-century before it could be applied to humans. [1]. Hans Berger, the German psychiatrist, pioneered EEG (electroencephalography) in humans. He developed a recording technique by attaching an electrode to the scalp, similar to how it is done now. Berger was the first person to noninvasively record the electrical activity of the human brain. [2]. One of Berger's great discoveries was that the brain emits different electrical waves. In 1929 he published his first paper on EEG, "Über das Elektrenkephalogramm des Menschen", in which he named them alpha and beta waves. These definitions remain an important part of modern EEG analysis. [2]

By the 1960s, digital equipment was available that allowed, for example, the application of Fourier analysis to EEG data and the extraction of spectral or frequency content for the signal. Advances in technology meant that the data could be analysed in much greater detail, also because of the larger number of electrodes. [3].

The concept of neurofeedback emerged, which was about training users to control their brain frequencies using auditory or visual feedback. The most popular training was alpha versus theta, where users trained their minds to produce more alpha waves and fewer theta waves. [3]

Recent advances in BCI research suggest that new and innovative developments or combined solutions using EEG and BCI or eye-head tracking technology could emerge in the near future. The successes of EEG and the possibility of developing new BCI systems have clearly provided a boost to the research field, which is being pursued by a large number of researchers in a variety of fields, such as neuroscientists, physicians, electrical engineers, and clinical rehabilitation specialists. Currently, many researchers are conducting studies on the use of EEG devices, such as Epoc helms. Ramirez and Vamvakousis in their studies [5] conducted research on the machine learning approach to detect emotions from brain activity, recorded as an electroencephalograph (EEG) with the Emotic Epoc device, during auditory stimulation. Benitez et al. [6] conducted research using the Emotiv EPOC to acquire raw EEG signals and proposes an automatic eyewink interpretation system based on raw EEG signal analysis for the human-machine interface as a possible aid for people with disabilities. Ranky and Adamovich [7] used in their research Emotiv EPOC to control an external robotic arm to determine if it was suitable for peripheral control. Badcock et al. [8] used Emotiv EPOC to measure auditor quality research ERPs. Babusiak et al. [9] described an investigation of brain activity while playeing a serious game. Almagor et al. [10] in their reserch used autoencoders to denoise cross-session non-stationarity in EEG based motor imagery BCI. Rosipal et al. [11] presented their BCI system with a head-mounted virtual reality display for the motor rehabilitation of patients with stroke. Zakrzewski, Stasiak and Wojciechowski [12] presented in their research EEG-based BCI designed for classification of motor imagery tasks. Koreko et al. [13] conducted an experiment to evaluate the capacity of a 3D virtual space to stimulate cognitive functions, where they created two game prototypes, where they used EEG measurements.

EEG devices

When selecting EEG equipment, we must take into account several aspects that can affect the resulting measurements and the price of the equipment itself. Categorising devices by price is probably the simplest, with the rule that the more expensive the device, the better the quality.

Inexpensive devices include NeuroSky and Muse. They offer neurofeedback solutions to help improve meditation and sleep, although the research potential of these devices is ultimately limited. OpenBCI's devices originated as a startup, but they have expanded the original concept to include an open source 3D printed cap. Emotiv devices are also available as wireless devices, which gives the respondent the ability to move more freely.

Mid-range devices offer a greater number of channels and operate without the use of a conductive solution, accelerating both the handling of the device and the actual experience of use. This includes devices from ANT Neuro, Cognionics, G.tec, Neuroelectrics, and Wearable Sensing.

High-price devices have a large number of electrode channels. This includes devices from Brain Product, BioSema. These systems represent the highest quality EEG devices currently available.

II. Game Development

Ordinary households are already fairly well equipped with ICT devices - they have one or more computers, mobile devices (mobiles, tablets), some even have game consoles. Gaming, not only among children, is quite common nowadays.

When we want to create games, we have different game engines at our disposal. The two most dominant free environments currently available for non-commercial use are Unity and Unreal Engine.

Both are so-called cross-platform engines, which means that we can use them to develop and then export games for multiple types of devices and systems. It is possible to create 3D and 2D scenes in the programme [14].

These game engines also support various user-experience devices. For example, we can create a game or an app that we control with eye tracking devices or even apps controlled by EEG helmets.

A. *EEG devices*

In our application, we decided to use the Unity environment for creating an app controlled by EEG helmets, Emotiv Epoc+, which consists of 14 channel EEG, 9 axis motion sensors, and could be connected with Bluetooth Low Energy. Figure 1 shows Epoc+ device.

Fig. 1. Emotive Epoc+ device.

B. *Connection and communication of Emotive devices with BCI and Unity development*

To connect the EEG helmets of Emotive with the Unity environment, we need to implement a special extension using the Cortex API in the Unity environment, which ensures communication with the Emotiv BCI programme, in which we have created an account and learnt commands. For communication via the Cortex API to work, it is necessary to create a new Cortex project on the manufacturer's official website. After the project is created, a unique project and client identifier will be generated along with a password.

The communication between the application created in Unity and the data from Emotiv BCI was done within the local network via WebSocket. Processing of the transmitted data was done with the help of three main scripts. BrainFramework, EventManager, and Response.

In the main BrainFramework script, values are initially assigned to the following variables:

- socketUrl – WebSocket url on which the communication will take place,
- clientId - client identifier created in the Cortex project,
- clientSecret – client password created in the Cortex project,
- headsetId – Emotiv device identifier,
- profile – the name of the account in the Emotiv BCI.

Furthermore, the script defines variables for communication and a new class for easier handling of Emotiv BCI commands. An important function that is called first before communication starts is "Start()". This function has the task of establishing communication based on a sequence of calls to other functions to perform the following actions:

- Verify that the user exists, and, if so, try to log them in;
- verify that the user has the necessary access and permissions;
- If the previous points are met, load the user's profile with his learnt command;
- If the previous points are met, the result is a working communication link.

Once the connection is successfully established, communication begins with data and commands sent from the Emotiv BCI programme. Figure 2 shows the code of the Start() function.

```
void Start(){
   Connect();
   On("UserLoggedIn", requestAccess);
   On("AccessGranted", authorize);
   On("Authorized", createSession);
   On("SessionCreated", () => { loadProfile("load"); });
}

private void Connect(){
   WS = new WebSocket(socketUrl);
   WS.OnOpen += _open;
   WS.OnMessage += _message;
   WS.OnClose += _close;
   WS.ConnectAsync();
}
```

Fig. 2. Unity methods for EEG communication.

Once the connection is successfully established, communication is initiated, and the programme Emotiv BCI starts sending data and commands, which are filtered by the "_message" function, and all sequentially intercepted commands are assigned in the class instance "BRAIN_CLASS" according to their categorisation from the Emotiv BCI programme command, eyeAction, upperFaceAction, and lowerFaceAction.

Figure 3 shows the message function.

```
private void _message(object sender, MessageEventArgs e){
  RES_CLASS msg = JsonUtility.FromJson<RES_CLASS>(e.Data.ToString());
  if (msg.com != null){
    BRAIN.command = msg.com[0].ToString();
  }
  if (msg.fac != null){
    BRAIN.eyeAction = msg.fac[0].ToString();
    BRAIN.upperFaceAction = msg.fac[1].ToString();
    BRAIN.lowerFaceAction = msg.fac[3].ToString();
  }
}
```

Fig. 3. Message function for communication between Emotive BCI and Unity.

III. The Ball and Mind Game

In the analyzation phase of our application we defined a few requirements that our game should meet: compatible with Windows 10 (most of the computers with operating system Windows have this version), executable without installation, and must work with Emotiv's devices Insight, Epoc, Flex. The game should include easy navigation, and the actual control and gameplay should not be complicated.

We have designed a game concept where the player's task is to navigate a ball from start to finish through a maze, with three levels available. The game changes the difficulty of the game, which increases as the level increases. To make it not as easy for the player, the levels gradually remove the safety walls that serve as a barrier against falling out of the maze, which means the end of the game for the player.

The process of creating our game was divided into the phase of preparing the graphic elements, programming the functionalities, and testing the functionality. For the actual creation, we needed to have Unity version 2021.2.16f1 installed on the computer, the Emotiv Launcher, and a new Unity 2D project created with the "Brain Framework" extension imported, which is very important because without it the communication with the Emotiv devices would not work. The extension itself contains all the necessary components for the proper functioning of the communication, and also practical demonstrations of how to use and link the code with Emotiv devices.

A. *The opening scene*

The opening scene also includes marble and textual information that the player can move the marble left and right using the learnt Emotiv BCI commands. Figure 4 shows the opening scene.

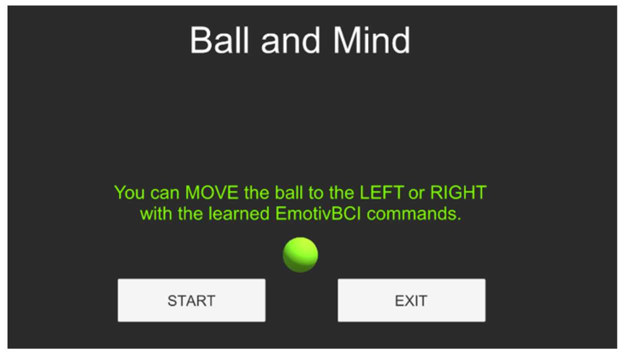

Fig. 4. Menu screen of our application.

B. *Game scene and game levels*

The principle of the game itself is about getting from the start to the finish line, where the user has to collect the highest possible score, and the maximum number of attempts is set at 3 lives. It is necessary to display this information to the player. That is why we added them to the top panel, where there is also a button that can be used to get to the opening scene. The upper panel is the playing surface. When launched, the player's green ball is placed in the starting position in the upper left corner of the scene. Below the starting platform, other platforms are available, which form several possible paths that the player can take to reach the destination. Figure 5 shows the playing surface of the game.

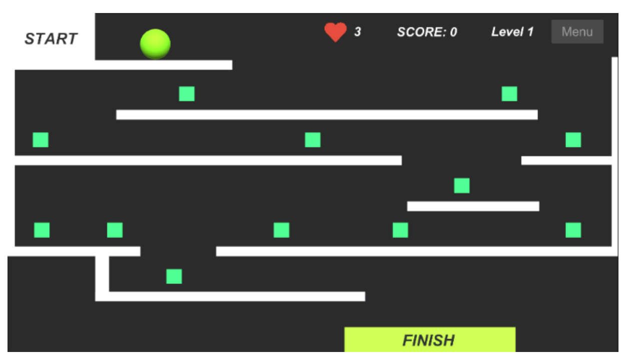

Fig. 5. Play surface of the game.

Green boxes on the platforms add scores when the player's ball passes through the box, with only one box adding one score at a time.

The player can restart the game and start again from the first level or return to the opening scene. Figure 6 shows the panel when the player's lives are spent.

Fig. 6. Game over window of our game.

When the player manages to cross the finish line on the yellow platform marked "Finish", the next level is loaded (there are three available levels).

If the player reaches the finish at level three, they will be shown a success bar with information about the score they have achieved. The player can then either restart the game and start over from the first level or return to the opening scene. Figure 7 shows the panel after successfully completing the game.

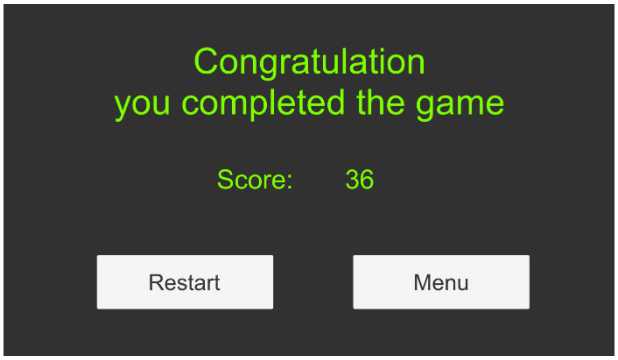

Fig. 7. Screen with the completion of the game successfully.

C. Game Testing

A total of fourteen people of different ages and genders tested the game on the Emotiv Epoc device. For six respondents, there was a problem with the initial settings that was caused by poor contact of the sensors with the scalp because the respondents had long or thick hair. One respondent was unable to successfully make the initial settings and so was unable to continue.

Before playing the game, the respondents had to perform a command learning process where they learnt to move an object to the right and left. They rated the learning process as very difficult and lengthy and some started to show signs of nervousness and mild aggression. On average, it took one respondent one hour to learn one command.

The overall evaluation of our game was very favourable and the game received a good response, and the respondents would like to play it at home but with the classic computer keyboard control, as the control using Emotiv devices was a problem for them and they did not enjoy the gaming experience enough.

To get better feedback from the respondents who tested the game, we developed an online form with nine questions and additional space for them to express their opinion.

Thirteen respondents completed the questionnaire. Our plan was to test on a larger sample of respondents, but due to the situation with the Covid-19 pandemic and the more difficult preparation before testing, unfortunately this was not possible.

Figure 8 shows a graph of the responses to the question of whether they had ever heard of playing a computer game using EEG, where most of the respondents said no. Figure 9 shows a graph of the responses for our next question, whether the respondents had ever tried playing a computer game using EEG, and all answered that they had not.

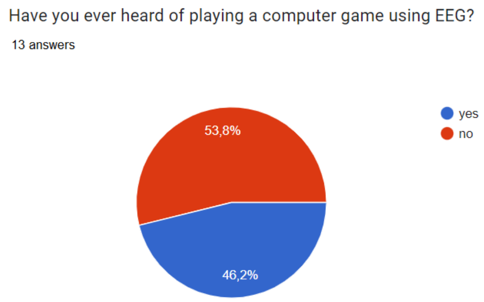

Fig. 8. The questionnaire question: Have you ever played a computer game using EEG?

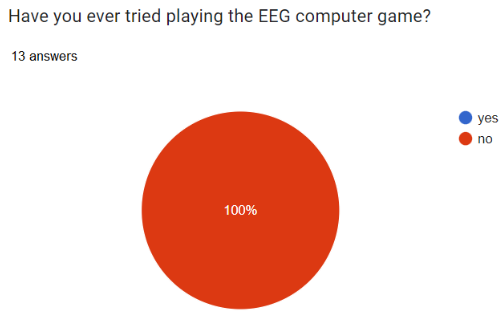

Fig. 9. The questionnaire question: Have you ever tried playing the EEG computer game?

To the question "What the respondents liked about our game?", they answered as follows: simple and clear design, it was something new and interesting for them, playing through the levels.

To the question "What the respondents did not like about our game?" they answered: only 3 levels were available, unusual, and harder to control, and no history of the recorded score.

From the responses to our questionnaire, it seems that we should add the functionality to record the scores in the history, so that the player can later see what scores he was able to record in the past. We should also add more levels to the game. We cannot control the actual control problems using the learned commands.

IV. OBJECTOR OF MIND GAME

Similarly to the previous game, we defined the same requirements for this second game: minimum compatibility with the Windows 10, the ability to run the game without installation, and game control using Emotive devices (Insight, Epoc, Flex). The game should contain simple navigation, and the control and playing of the game itself should not be complicated. Music and sound effects should be available in the game, and the volume for music and sound effects should be adjustable separately.

We designed a game concept where the player controls a cube with which he can move edgeways, while coming to him are walls separated by a gap, which the player must hit in order to avoid the impact and successfully pass the obstacle. The player's task is also to collect as many points and bonus tokens as possible, for which he can then buy improvements in the store that can be used while playing the game.

We have divided the process of creating our game into a phase of preparing graphic elements, programming functionalities, and testing functionality. We used the same version of Unity, Emotive Launcher programmeme, and the extension "Brain Framework" as for the game "The Ball and Mind" to create the second game.

A. The opening scene, daily reward, score, and settings

We started the creation with the opening scene, which is displayed immediately after turning on the application. Figure 10 shows the opening scene. In the opening scene, there are buttons:

- Start – starting the game,
- Score – scene with table top 5 scores,
- Exit – the game shuts down,
- Shop image – a scene with a shop,
- Setting image – loads the settings scene.

Fig. 10. Menu screen of our application.

An important part of the opening scene is also the display of lives that the player has available and can use while playing the game if he encounters an obstacle. Once every 24 hours, after turning on the game, a panel will appear in the opening scene, which informs the player about obtaining a daily reward, namely: 2 lives and 10 tokens. Figure 11 shows the daily reward panel.

Fig. 11. Daily reward screen.

To prevent abuse of this functionality based on date and time changes on the local computer, the time data are obtained from an external source in the "TimeManager" script. Getting from an external source is done in the "GetTime()" function. Figure 12 shows the script code.

```
public void RewardClicked(){
  ClaimReward();
  SecurePlayerPrefs.SetString("_timer_daily_visit_reward", "Standby");
  StartCoroutine("CheckTime");
}

private void ClaimReward(){
  FadeOut = true;
  Lives = SecurePlayerPrefs.GetInt("playerLives", 0);
  Lives += LivesReward;
  Golds = SecurePlayerPrefs.GetInt("playerGolds", 0);
  Golds += GoldReward;
  SecurePlayerPrefs.SetInt("playerLives", Lives);
  SecurePlayerPrefs.SetInt("playerGolds", Golds);
  SecurePlayerPrefs.Save();
}
```

Fig. 12. Code for reward functionality.

Figure 13 shows the setting scene.

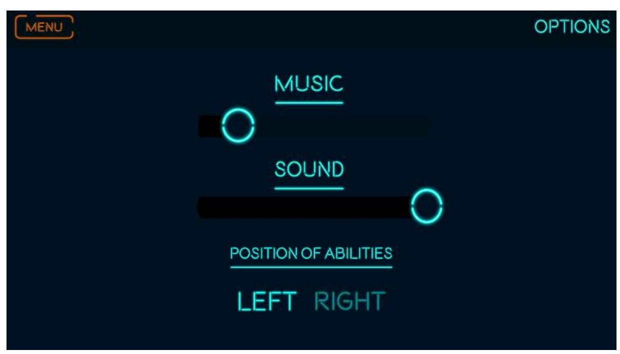

Fig. 13. Setting scene of the game.

Figure 14 shows the score table.

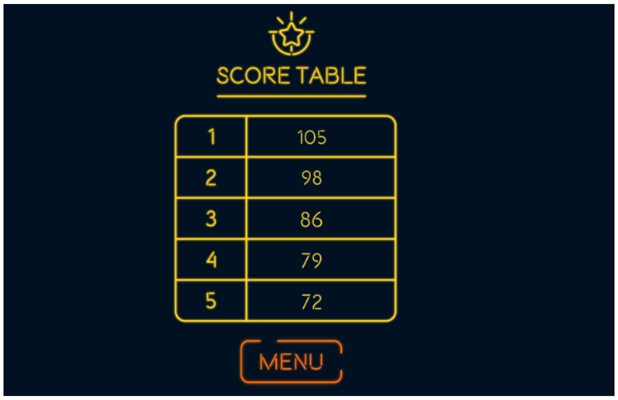

Fig. 14. Scene with score table.

The player can use the tokens collected to buy upgrades in the store that will help him to achieve the highest possible score in the game. There are three options to choose from in the store:

- Defence shield - costs 15 tokens, once activated, the player can pass through obstacles,
- Slowdown - costs 10 tokens, when activated slows down the arrival of obstacles,
- Acceleration - costs 10 tokens, when activated, the arrival of obstacles will be accelerated.

To buy an upgrade, the player must click on the "Buy" button, which will call the function belonging to the given upgrade. The function checks if the player has enough tokens. If so, then the number of specific improvements will increase by one piece and the number of player tokens will be decreased by the specified amount. Figure 15 shows a scene with a shop.

Fig. 15. Shop scene for buying game upgrades.

B. *Game scene and game levels*

The principle of the game itself is about moving a cube and trying to avoid obstacles which come to the player with some gap. The player has to collect as many points and bonus tokens as possible, for which he can then buy improvements in the store that can be used while playing the game. Figure 16 shows the beginning of the game (countdown).

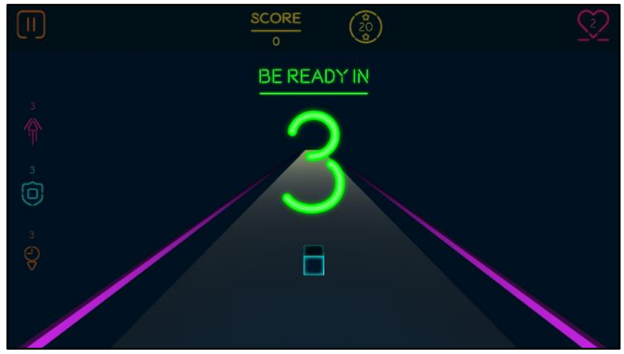

Fig. 16. Countdown of the game.

Figure 17 shows the main game scene.

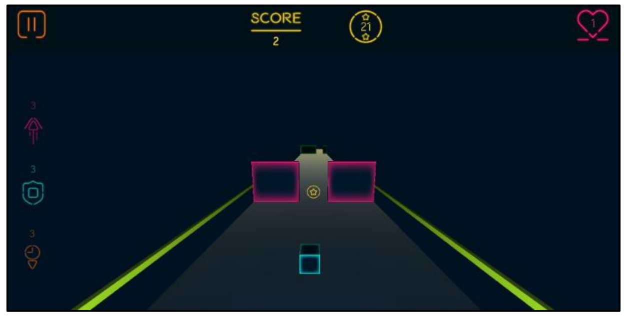

Fig. 17. Main screen – merge with obstacles.

Obstacles are created on the playing platform with a randomly placed gap through which the player must pass. The speed of creating obstacles increases as time increases, while the gap between obstacles also gradually narrows.

A player's cube can collide with multiple types of objects. The collision is evaluated using the "OnCollisionEnter" function and then comparing the tag of the object in the collision. Collisions with an object marked "AddScore" will increase the player's score by one point. Collisions with an object marked "AddGold" increase the number of tokens by one. If a collision occurs with an object marked "Enemy" and the player does not have a shield activated, it will be checked to see if they have available lives, and if they do, they will be shown a panel telling them if they want to use one life and continue. If the player has no more life or does not want to use it, the game ends, and a panel with the achieved score is displayed. Figure 18 shows a panel with the possibility of spending a life to continue the game.

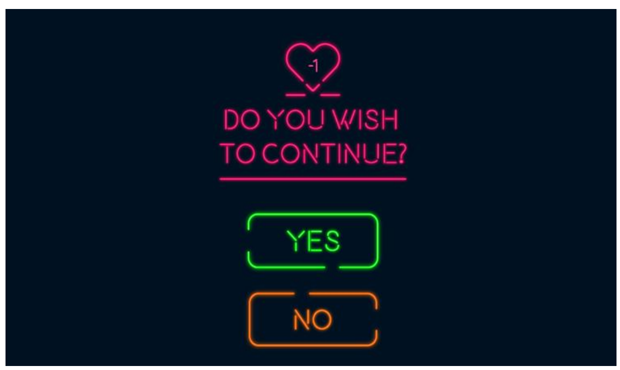

Fig. 18. Game over screen.

C. Game Testing

Fourteen people of different ages and genders tested the game again.

Similarly to when testing the game "Ball and Mind", the respondents had to perform a process of learning commands when they learnt to move an object to the right and left. After successfully completing the command learning phase, the respondents started playing and testing the Objector of Mind game. The general evaluation of our game was again very positive, and the game received an even better response than the first Ball and Mind game. Respondents could imagine it as a good game that they would play at home, but with classic control using a computer keyboard, because control using Emotive devices was a problem for them and they did not enjoy the game experience to a sufficient extent.

When asked what the respondents liked about our game, they answered as follows: nicely processed graphics and the overall concept of the game, it was something new and interesting for them.

When asked what the respondents did not like about our game, they responded as follows: there could be more visual and sound effects, sometimes the hit boxes on obstacles did not work correctly, and they also expressed dissatisfaction with the control using EEG.

From the answers to our questions in the questionnaire it follows that we should add more visual and sound effects. We should also check and possibly correct the correct functioning of the hit boxes on obstacles. We cannot influence problems with the control itself using learnt commands.

V. Conclusions

In the article, we briefly analyse the possibilities of using EEG and BCI technologies to control games using Emotiv helmets. We described two created games that can be controlled using Emotiv devices: Insight, Epoc, Flex. Unity, the development program with an implemented extension for communicating and capture learned commands from the Emotiv BCI program, was used to create the games. The created games are especially suitable for people who want to try a new way of controlling computer games. Based on the answers to the questionnaire, we think that EEG devices could be interesting tools for future games. We will continue to create other games controlled by these devices.

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